# INVESTIGATION OF THE 3-D HYDROGEN FLAME STRUCTURE IN A SUPERSONIC HIGH-TEMPERATURE AIR FLOW BY OPTICAL METHODS

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To organize hydrogen combustion in a supersonic air flow it is important to have the information on spatial distribution of combustion intensity. Such information allows one to judge the combustion process at any points of the plume to investigate the influence of various parameters on intensity of heat release, and also interrelation of the latter with the gas dynamical structure of the flow. All this is necessary to know for organization of an effective hydrogen burning process. However, the presence of high velocities and temperatures to be typical conditions for combustor of a hypersonic flight vehicle engines makes difficult an application not only contact methods, but also many optical ones.

In this work the experimental results of research of a plume structure at axial hydrogen injection in a supersonic high-temperature air jet are presented. Two levels of temperatures are compared. One of them (1500-2000 K) is usually achieved in the ground experimental facility with a long period of action. The other level of temperature (2500-2700 K) is characteristic for installations with a short period of action.

The experiments were carried out in ITAM SB RAS on a bench of supersonic combustion with an electric arc heating of air [1, 2]. Hot air heated up in the electric arc heater to the temperature level ensuring spontaneous combustion of hydrogen was blown out through the supersonic nozzle ($M = 2.2$; $R = 25$ mm) in a free space and further went in an ejector. The cold hydrogen was blown out through the injector located on an axis of air flow and representing a cylindrical tube with an inner diameter 8 mm and outer 10 mm. The expenditures made up to 1 kg/s of air and 1,5-4 g/s of hydrogen.

In cold air the visualization of flow was carried out by a conventional shadow method (device IAB-451). At the same time for the heated up air jet (at constant other parameters) it is considerably more difficult to receive the information about an internal structure by that method because of development of a high-power mixing layer, which chaotically distorts a course of beams. Own radiation of a flame in visible and ultra-violet areas of spectrum [3] therefore has been registered. For ultra-violet radiation the optical-mechanical scanner was used which has allowed to register two-dimensional distribution of an emission intensity of a flame in range of the wave lengths of 260-380 nм, that corresponds to radiation of the OH radical [4]. Its luminescence time equals only to $10^{-8}$ s that enables to identify its radiation precisely with zones of chemical reaction [5]. For an "average" level of temperatures of a supersonic air flow the main combustion was observed in a central part of a jet in zones of increase of pressure and temperature behind shock waves [6, 7]. The direct visualization of a hydrogen plume in visible area of a spectrum was conducted by the camera of technical vision, Fig. 1, a,b. The given camera with a receiving element of a matrix type had the image dimension of 400×500 points and worked in visible and near infrared range of wave lengths.

Among the investigated modes the special interest represent not enough studied cases with an especially high temperature level of airflow (up to 2500 K), Fig. 1, b. In the assumption of axisymmetry of current with the help of the Abel transformation the reconstruction of plume was made. For this the software package "Topaz-Micro" developed for gas and plasma

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a

b

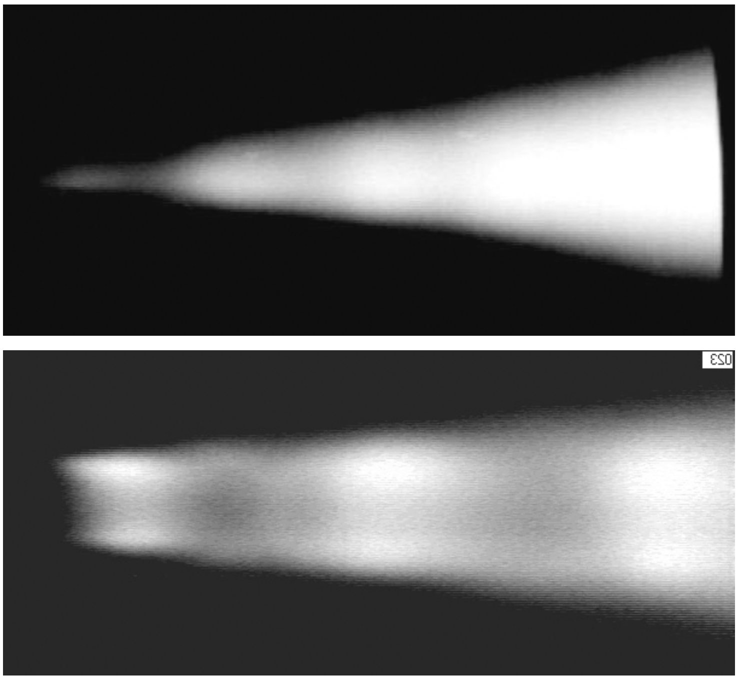

Figure 1. Direct photo of hydrogen flame, total temperature of coaxial air flow
a – 1850 K, b – 2600 K.

a

b

Figure 2. Reconstruction of 3-D hydrogen flame, $T_0 \geq 2500$ K.

tomography was used [8]. The structure of combustion zones obtained by that is shown on Fig. 2. a,b.

As it is visible on Figs. 1 and 2, with increasing of a flow temperature (from a level 1800-2000 up to 2500-2600 K) the structure of an initial part of plume has varied. The zones of the increased combustion intensity and also the ignition location are removed to outer area of a mixing layer, Fig. 2, a,b. The annular character of combustion is traced on an extent of at least first three "barrels" of a supersonic air jet. In comparison with the average level of temperatures (1500-2000 K), when the ignition occurs mainly in a central part of the jet behind shock waves, Fig.1.a, at high temperatures ($\geq$ 2500 K) the hydrogen is ignited since periphery of the hydrogen jet (in the beginning of mixing of hydrogen and air). On such modes the ignition location is fixed at the injector edge irrespective of the expenditure of cold hydrogen.

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